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Sandia National Laboratories
Small-Scale Sensitivity Testing (SSST) Report:

Various Recrystallizations of CL-20 (HNIW, hexanitrohexaazaisowurtzitane)

SNL-SSST-20151022

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1 Test Methods

1.1 Impact Sensitivity Testing

Impact sensitivity testing was performed using a modified Bureau of Mines (MBOM) impactor manufactured by Safety Management Services, Inc., shown in Figure 1. Type-12 tooling was utilized on this machine with a 2.5kg impactor and matching intermediate mass. This particular machine is capable of a maximum drop height of 115cm with 0.1cm increments, though 1cm increments are typically used. Sample material was placed (35 ± 2mg) onto 1 inch squares of Norton brand 180A Garnet sandpaper. Positive results were detected visually or audibly by the operator as smoke, flash, report, charring/tearing of the sandpaper, etc.

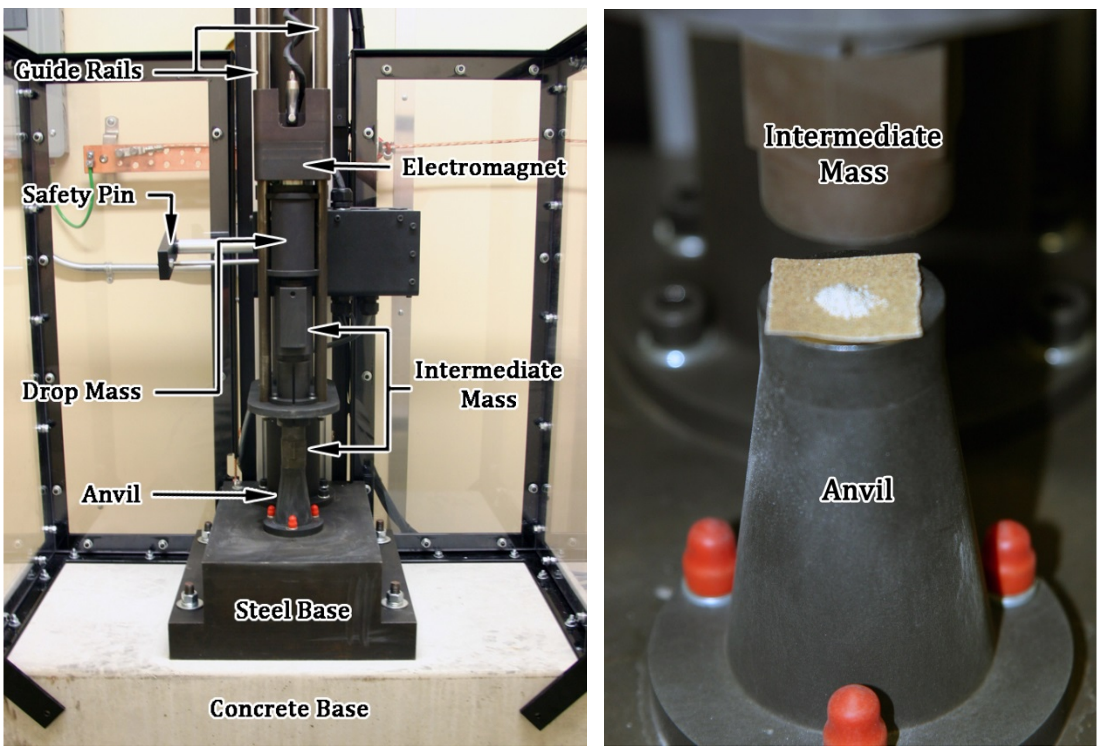

Figure 1. MBOM Impactor and Type-12 tooling overview

1.2 Friction Sensitivity Testing

Friction testing was conducted using a BAM machine manufactured by UTEC Corp, LLC, shown in Figure 2. A small amount of sample material (~10mm^3) is placed upon a porcelain plate affixed to an actuating base [1, 2]. A load is applied through a rounded porcelain pin clamped into a collet on the loading arm to which various weights are hung. When triggered, the base reciprocates through 10mm of movement (Figure 2).

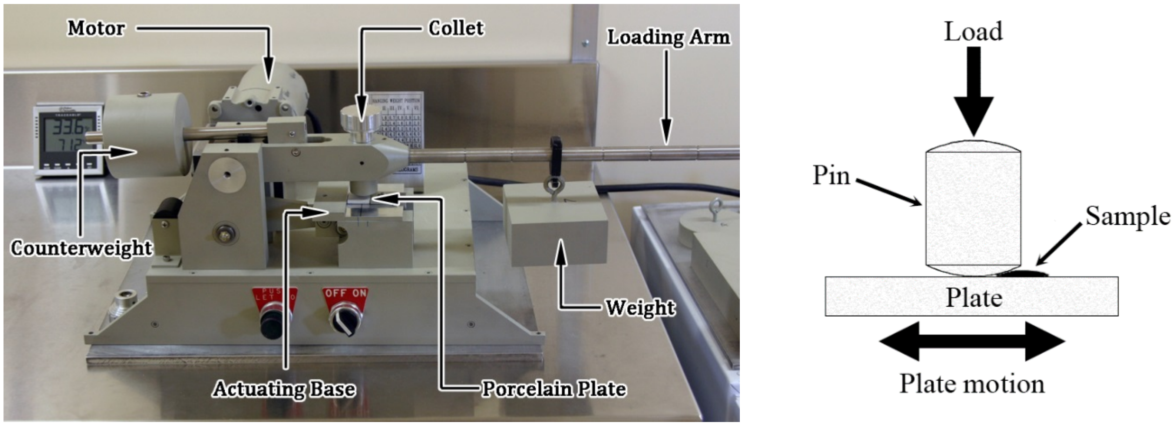

Figure 2. The BAM friction tester and mechanism

Porcelain pins and plates are manufactured by Reichel & Partner, GmbH. Stimulus levels are shown in Table 1.

Table 1. Stimulus levels (kg) for the BAM friction tester

0.5	0.6	0.7	0.8	0.9	1.0
1.2	1.4	1.6	1.8	2.0	2.4
2.8	3.0	3.2	3.6	4.0	4.2
4.8	5.4	5.6	6.0	6.4	7.2
8.0	8.4	9.6	10.8	11.2	12.0
12.8	14.4	16.0	16.8	18.0	19.2
21.6	24.0	25.2	28.8	32.4	36.0

Positive results were detected visually or audibly by the operator as smoke, flash, pops, crackles, etc. The load, in Newtons is calculated by multiplying the stimulus level (kg) by ten.

1.3 ESD Sensitivity Testing

Electrostatic discharge (ESD) testing was conducted using an ABL (Alleghany Ballistics Laboratory) machine (Figure 3) manufactured by Safety Management Services, Inc. Voltage was held constant at 5000 ± 20V while capacitance was varied to adjust the energy levels. Typically used energy levels are shown in Table 2.

Figure 3. ABL-ESD tester and mechanism

Table 2. Energy levels (J) for the ABL-ESD tester

Capacitance (μF)	Energy at 5000V (J)
0.75	9.375
0.5	6.25
0.25	3.125
0.1	1.25
0.05	0.625
0.02	0.25
0.012	0.15
0.006	0.075
0.002	0.025
0.001	0.0125
0.0005	0.00625
0.0002	0.0025

Results were determined through the use of an infrared gas analyzer (CO_2/CO) - a model ZRE manufactured by California Analytical Instruments, Inc. A change in concentration greater than 40ppm for either gas was considered a positive reaction. A digital photograph was taken of each run as a supplemental record [3]. The specific camera used was a Nikon D90 DSLR camera utilizing a 200mm Nikkor lens. A one second exposure was taken during each trial.

1.4 Statistical Analyses

1.4.1 Bruceton Method

The Bruceton [4] analysis method determines the stimulus level at which there is a 50% chance of initiation (H_{50}). Also known as the Up-Down or Staircase Technique, a Bruceton consists of a minimum of 21 tests at varying stimulus levels for a sample material. The material response at a specific level dictates the next level to be tested. After a positive reaction (Go), the next lower level will be used. After a negative reaction (No Go), the stimulus is increased one level. Once the desired number of tests is completed, the 50% level and standard deviation are calculated. An example Bruceton analysis is shown in Figure 4, with the dashed line representing the calculated H_{50} of 48.4 ± 0.6 cm. Bruceton results are reported in comparison to results from well characterized materials such as PETN or RDX.

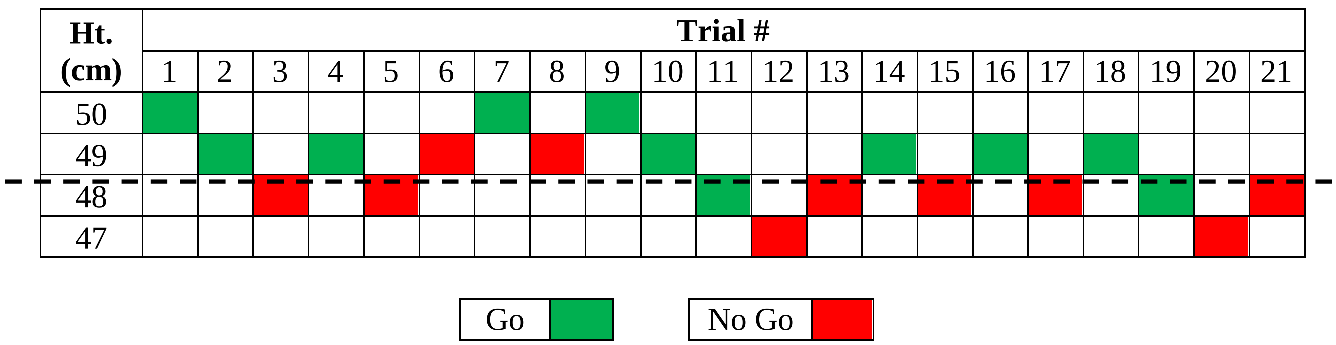

Figure 4. An example Bruceton and calculated H_{50} (dashed line)

1.4.2 TIL Method

This method determines the stimulus level at which zero reactions occur during twenty (or fewer) consecutive trials with at least one positive reaction at the next higher level. Operators typically begin at a higher stimulus level where a reaction is likely. Upon observation of a reaction (Go), the stimulus level is reduced by a single step. Upon observation of a non-reaction (No Go), the test is repeated at the same level. When 20 (for a 0 of 20 TIL) consecutive No Go’s at a single stimulus level are recorded, this level is reported as the TIL. A 0 of 20 TIL represents an approximately 3.4% chance of initiation at the reported stimulus level. An example BAM friction TIL with a final result of 160N (16.0kg) is shown in Figure 5. TIL results are typically reported with results from well-characterized materials such as PETN or RDX for comparative purposes.

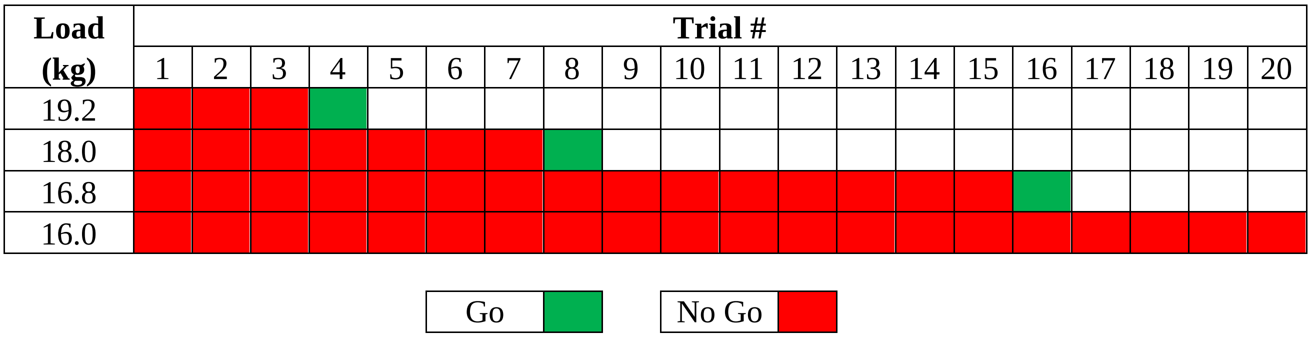

Figure 5. An example TIL, 0 of 20

2 Test Materials

Test materials consisted of multiple lots of CL-20 (HNIW) of variable particle sizes produced via recrystallization using various methods. Specific variances between recrystallization methods are detailed below.

Table 3. CL-20 lot recrystallization variances

Lot #	Variance
MM2545-40	Slow crash precipitation, 5g of 2µm seed crystals (2hr stirring post precipitation)
MM2594-48	Slow crash precipitation, 5g of MM2545-40 CL-20 seed crystals (1.5hr stirring post precipitation)
DMR-1103-#1-38	Rapid crash precipitation, no seed crystals
DMR-1103-#1-40	Slow crash precipitation, no seed crystals
DMR-1103-#1-44	Crash precipitated, attempt to produce β-CL-20 (30 seconds stirring post precipitation)
DMR-1103-#1-45	Same method as MM2545-40, except using 10% (wt.) 2µm seed crystals.

Multiple particle size analyses were conducted on each lot of CL-20 utilizing a Beckman-Coulter LS 13 320. Average particle size distribution plots for each lot are displayed below. SEM images are also presented for each lot, with additional higher magnification images of lots -44 and -45 presented for clarity.

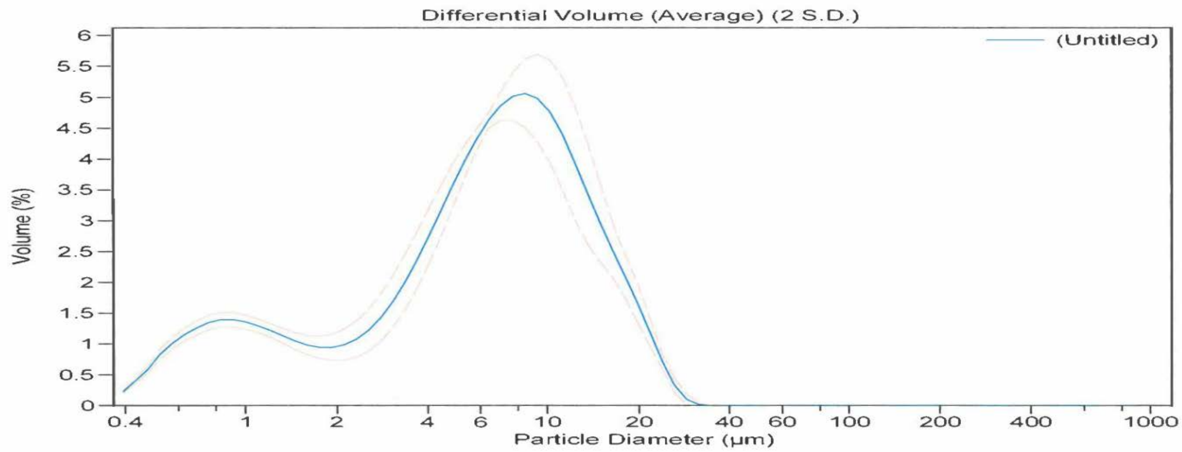

Figure 6. Average particle size distribution for Lot MM2545-40

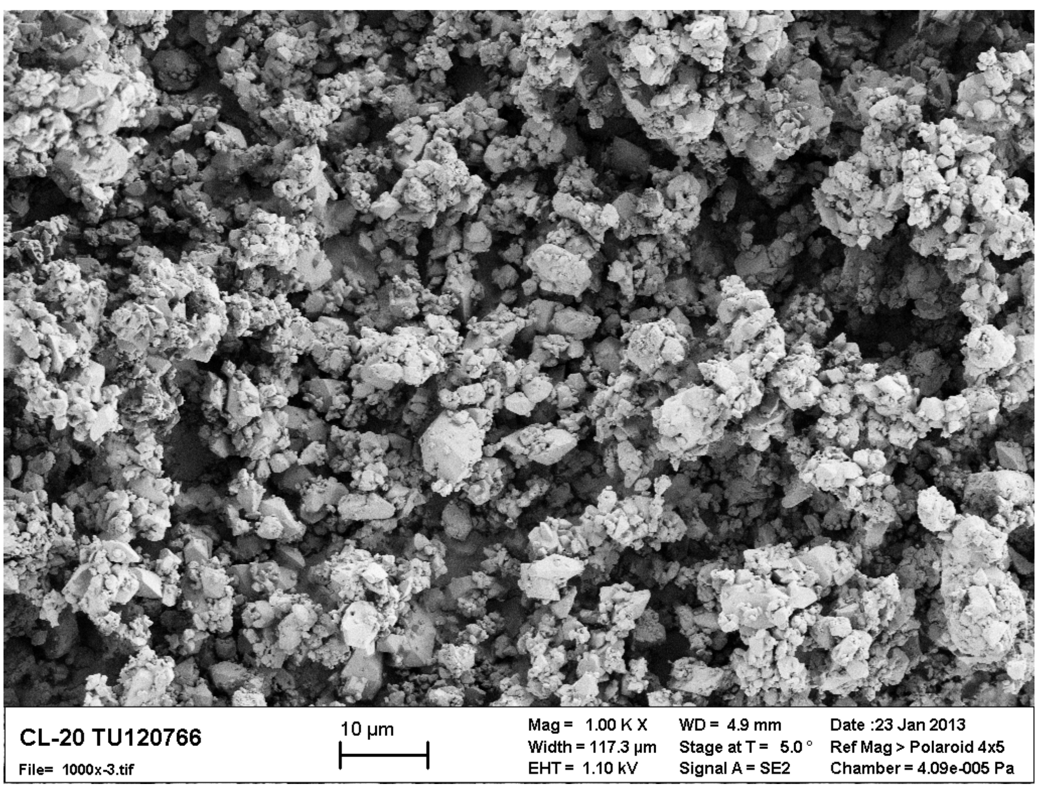

Figure 7. SEM image of Lot MM2545-40

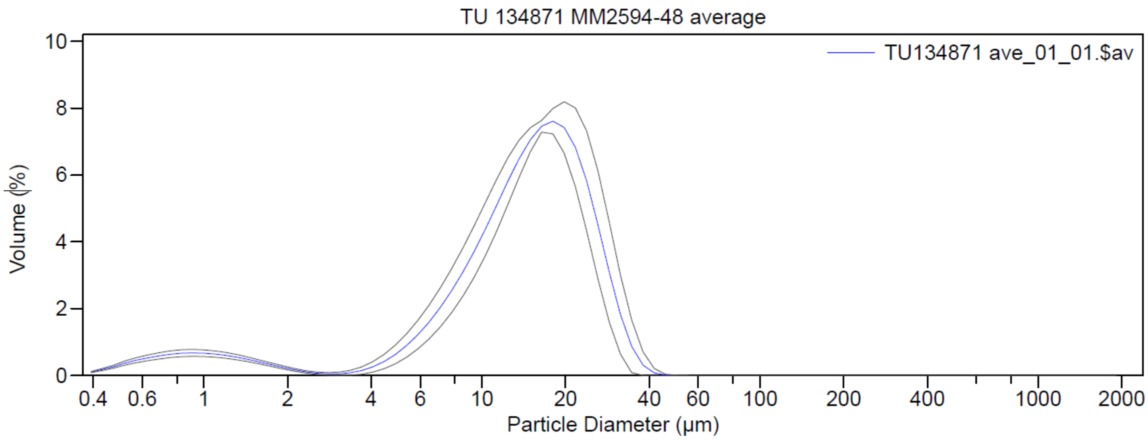

Figure 8. Average particle size distribution for Lot MM2594-48

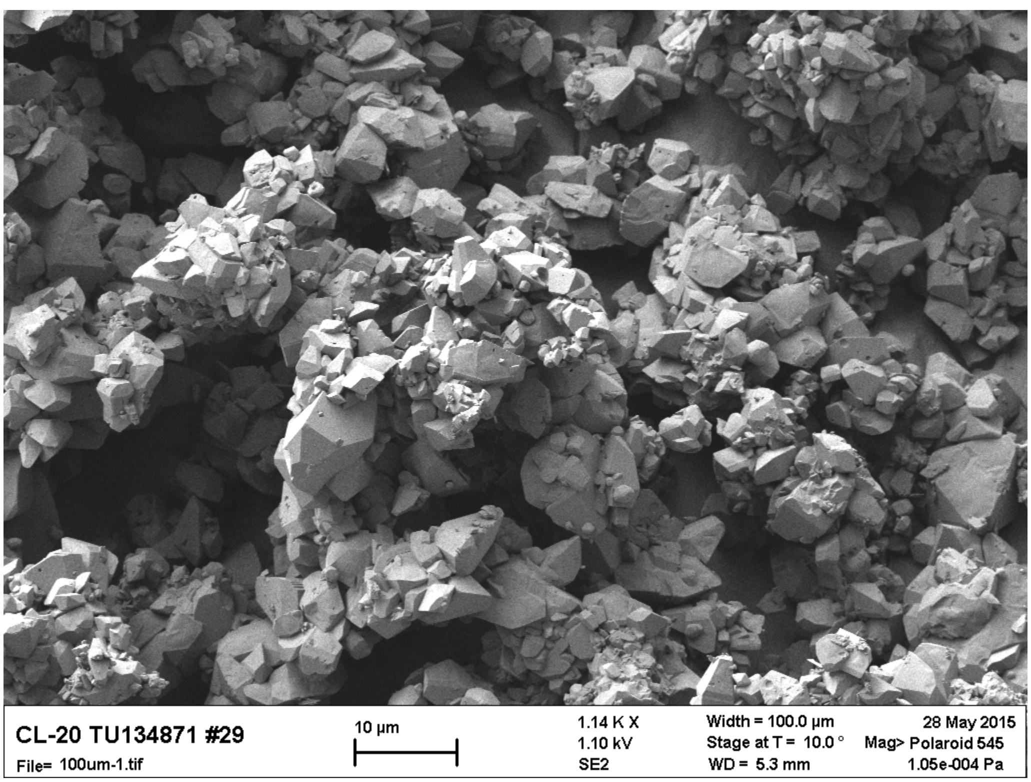

Figure 9. SEM image of Lot MM2594-48

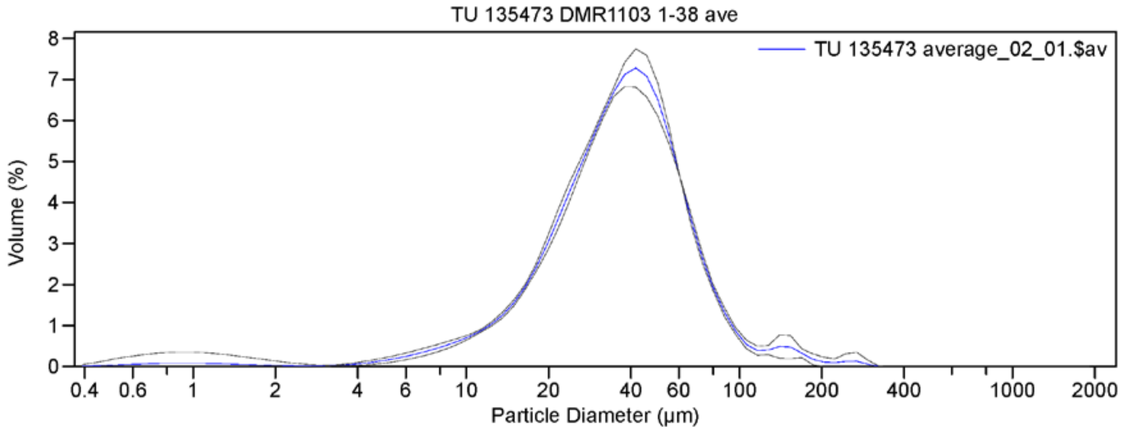

Figure 10. Average particle size distribution for Lot DMR-1103-#1-38

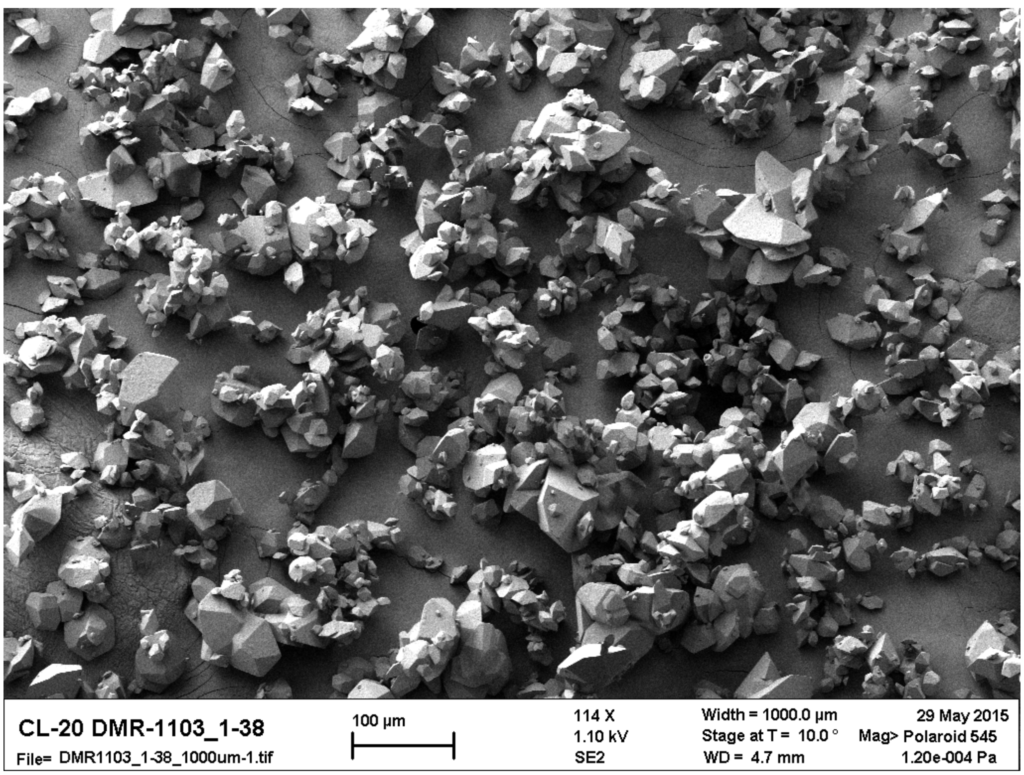

Figure 11. SEM image of Lot DMR-1103-#1-38

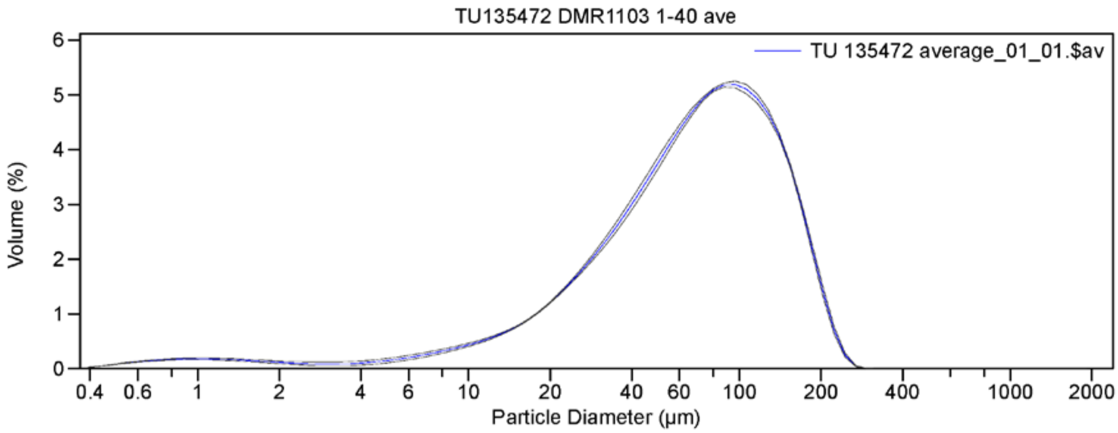

Figure 12. Average particle size distribution for Lot DMR-1103-#1-40

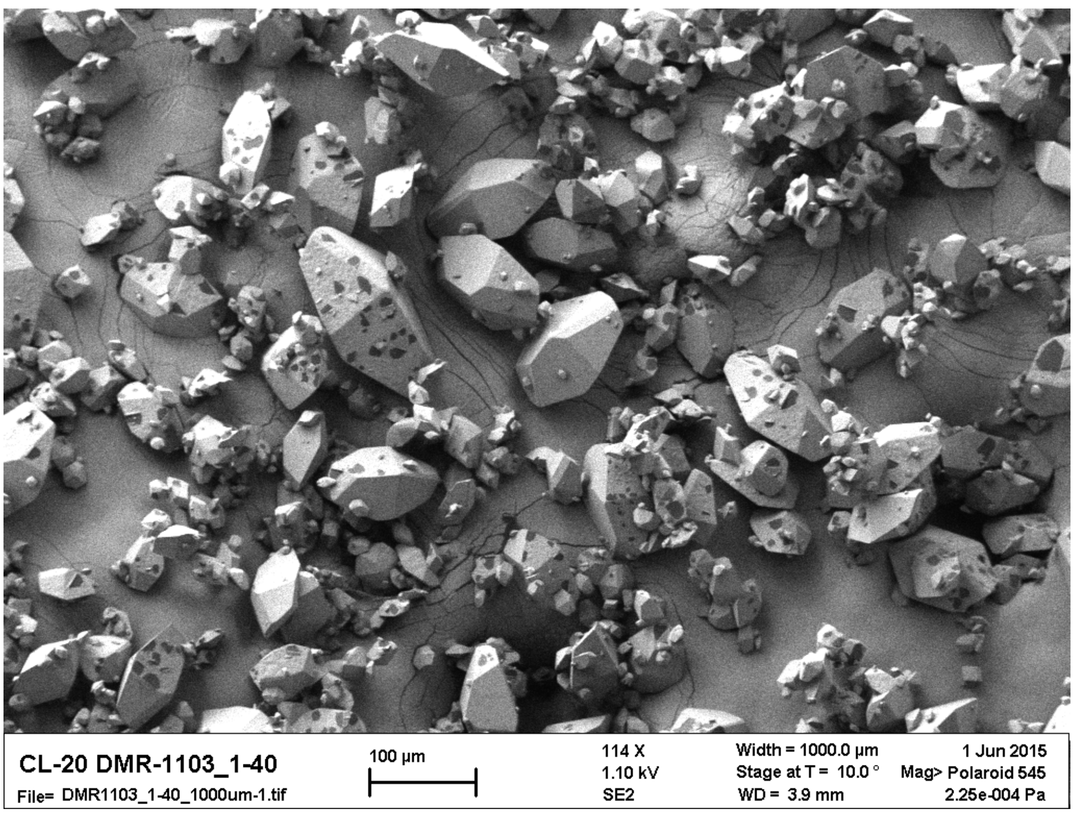

Figure 13. SEM image of Lot DMR-1103-#1-40

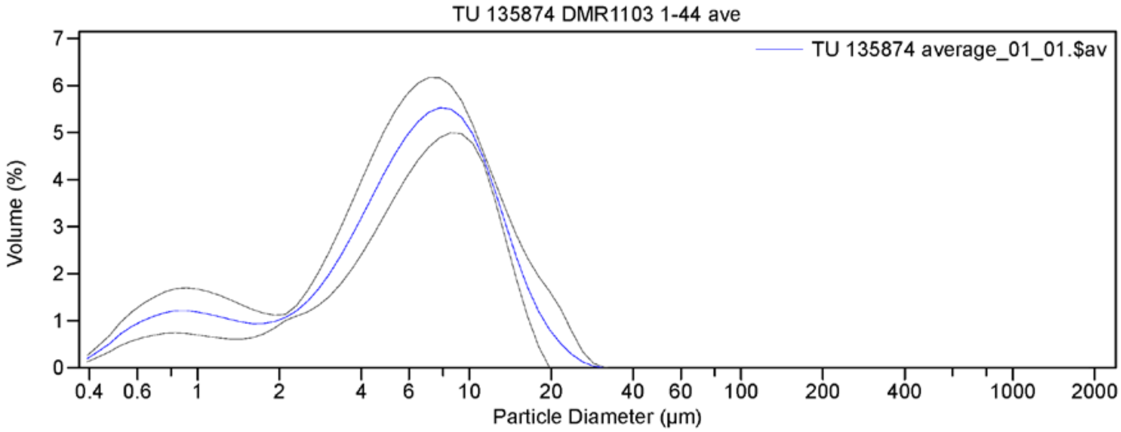

Figure 14. Average particle size distribution for Lot DMR-1103-#1-44

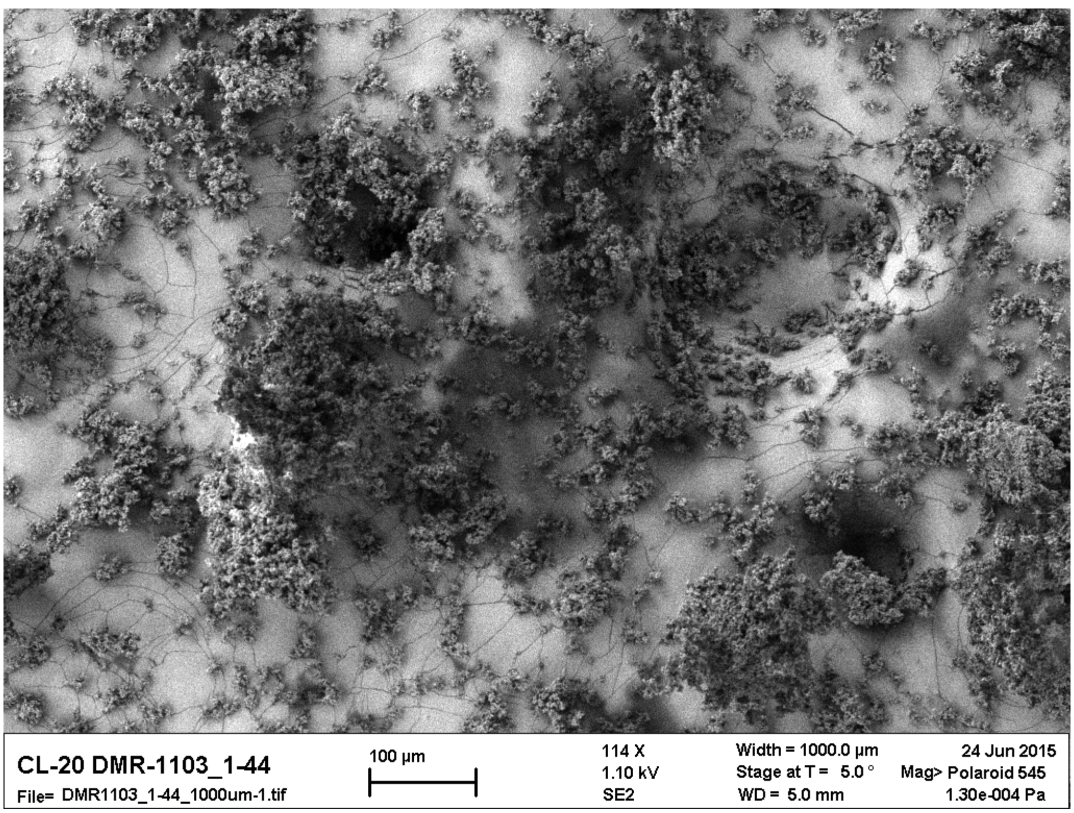

Figure 15. SEM image of Lot DMR-1103-#1-44

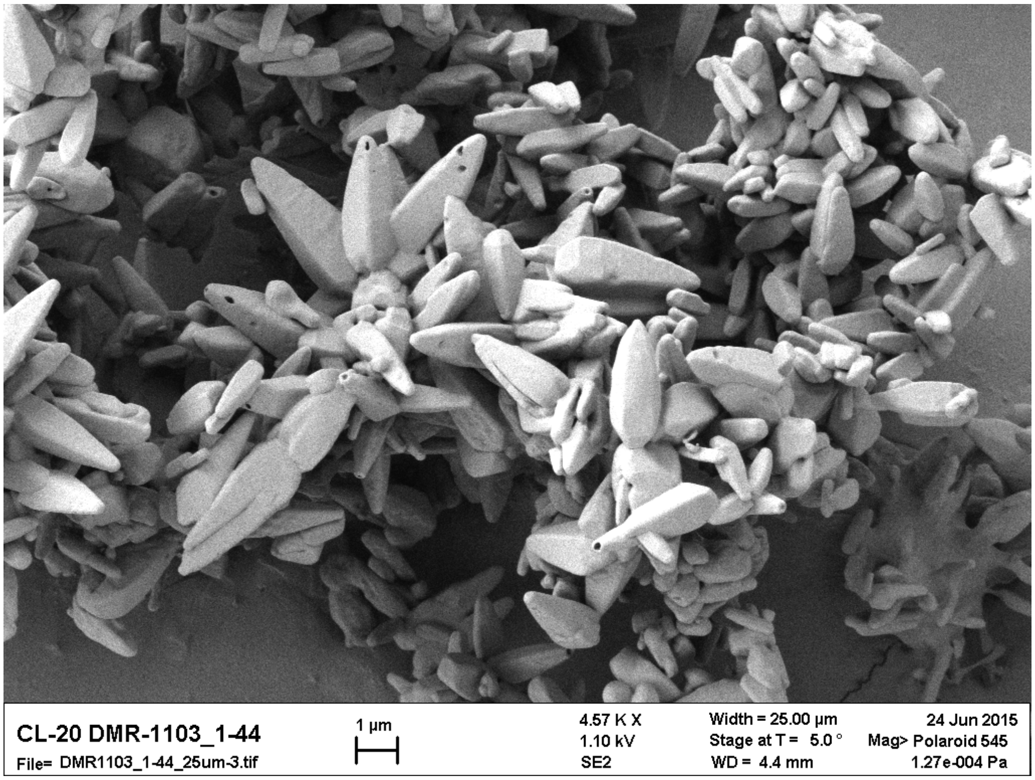

Figure 16. Higher magnification SEM image of Lot DMR-1103-#1-44

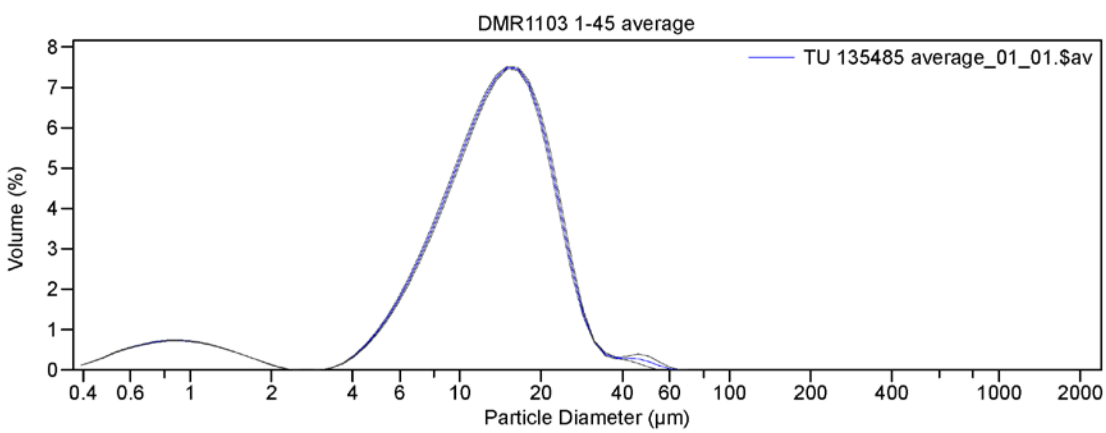

Figure 17. Average particle size distribution for Lot DMR-1103-#1-45

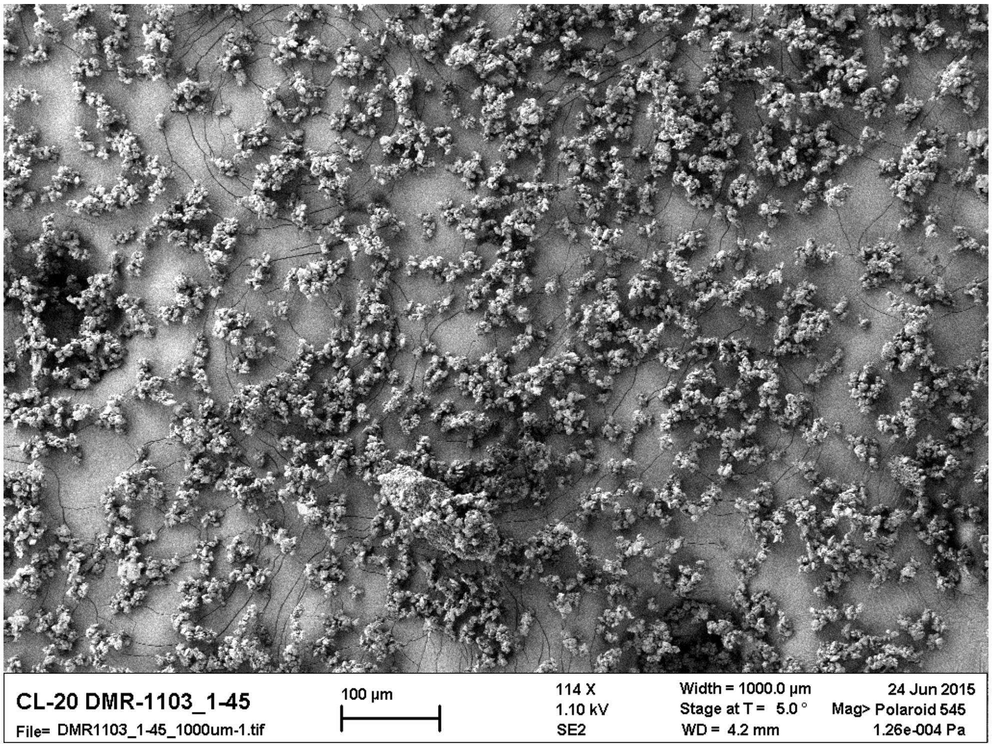

Figure 18. SEM image of Lot DMR-1103-#1-45

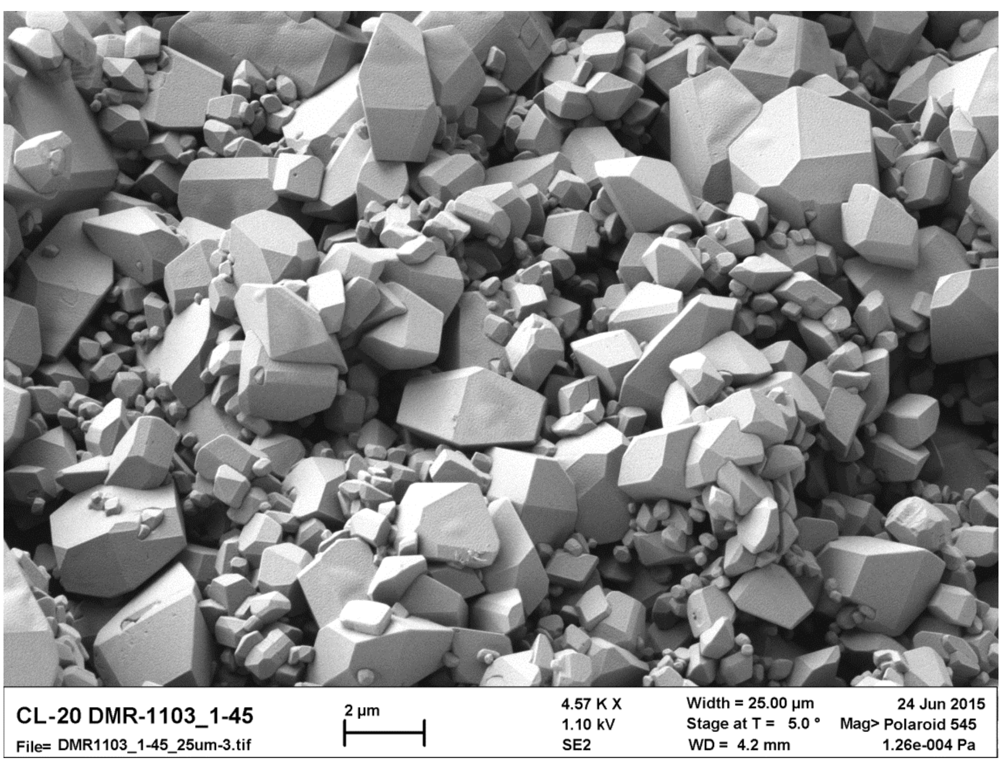

Figure 19. Higher magnification SEM image of Lot DMR-1103-#1-45

Mil-spec PETN (pentaerythritol tetranitrate) and RDX (cyclotrimethylenetrinitramine) data is provided for comparative purposes [5, 6]. All materials tested were dried prior to use.

3 Results

3.1 Impact Sensitivity Testing Results

Test results for impact sensitivity are shown below (Table 4).

Table 4. Impact sensitivity test results and conditions

Material	Test Date	H_{50} (cm)	Temp. (°C)	RH (%)
PETN*	Multiple	12.5 ± 0.8	22.3	35.1
RDX*	Multiple	23.3 ± 1.2	21.4	30.6
CL-20 (MM2545-40)	6/18/15	21.5 ± 1.3	23.8	43.7
CL-20 (MM2594-48)	6/15/15	72.6 ± 1.2	22.8	48.2
CL-20 (DMR-1103-#1-38)	9/4/15	20.6 ± 2.1	23.6	46.3
CL-20 (DMR-1103-#1-40)	8/19/15	14.9 ± 1.1	24.7	41.2
CL-20 (DMR-1103-#1-44)	8/4/15	19.6 ± 4.9	22.8	47.7
CL-20 (DMR-1103-#1-45)	8/5/15	25.5 ± 1.3	24.4	42.2

*Results averaged from multiple test series

3.2 Friction Sensitivity Testing Results

Test results for friction are tabulated below (Table 5).

Table 5. Friction sensitivity test results and conditions

Material	Test Date	TIL, 0 of 20 (N)	Temp. (°C)	RH (%)
PETN*	Multiple	33	20.9	37.5
RDX*	Multiple	164	21.6	30.1
CL-20 (MM2545-40)	6/25/15	56	23.7	53.4
CL-20 (MM2594-48)	6/16/15	80	22.8	53.8
CL-20 (DMR-1103-#1-38)	9/4/15	64	23.6	46.3
CL-20 (DMR-1103-#1-40)	8/20/15	54	24.6	44.3
CL-20 (DMR-1103-#1-44)	8/6/15	60	24.4	41.2
CL-20 (DMR-1103-#1-45)	8/6/15	72	24.4	41.2

*Results averaged from multiple test series

3.3 ESD Sensitivity Testing Results

Test results for ESD are tabulated below (Table 6).

Table 6. ESD sensitivity test results and conditions

Material	Test Date	TIL, 0 of 20 (J)	Temp. (°C)	RH (%)
PETN*	Multiple	0.125	23.1	43.2
RDX*	Multiple	0.150	20.6	25.4
CL-20 (MM2545-40)	6/17/15	0.075	22.6	54.2
CL-20 (MM2594-48)	6/16/15	0.15	22.7	55.3
CL-20 (DMR-1103-#1-38)	9/4/15	1.25	23.4	47.8
CL-20 (DMR-1103-#1-40)	8/24/15	0.625	23.7	51.4
CL-20 (DMR-1103-#1-44)	8/6/15	0.025	22.9	44.7
CL-20 (DMR-1103-#1-45)	8/7/15	0.075	22.9	46.2

*Results averaged from multiple test series

Due to varying particle size/geometry, these multiple lots of CL-20 displayed variable behavior in response to ESD stimulus. Besides the varying sensitivities shown in Table 6, the ignition behavior of each lot was particularly distinct.

Lots with larger comparative particle sizes displayed a very distinct ignition trace, as shown in Figure 12 and Figure 17. Slow burn traces of individual particles were easily captured during the one second exposure.

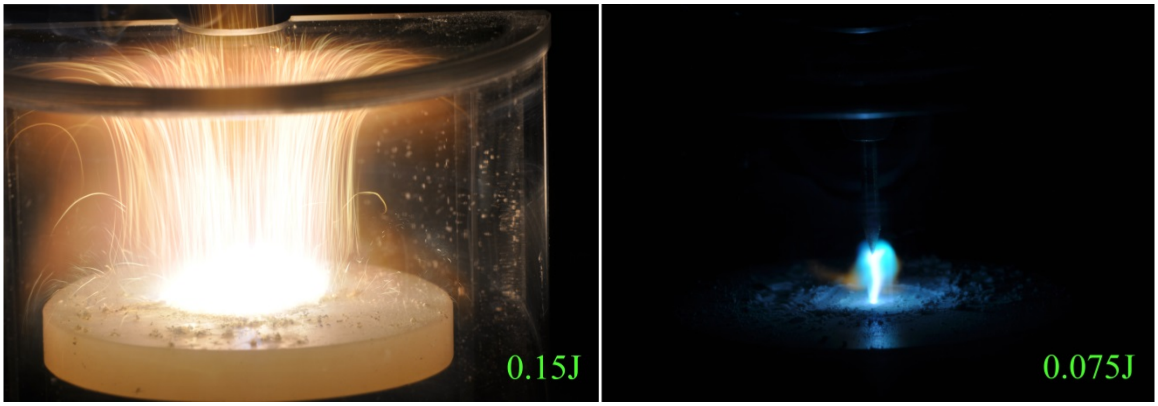

Figure 20. Lot MM2545-40 TIL+1 (Go) and TIL (No Go) level responses

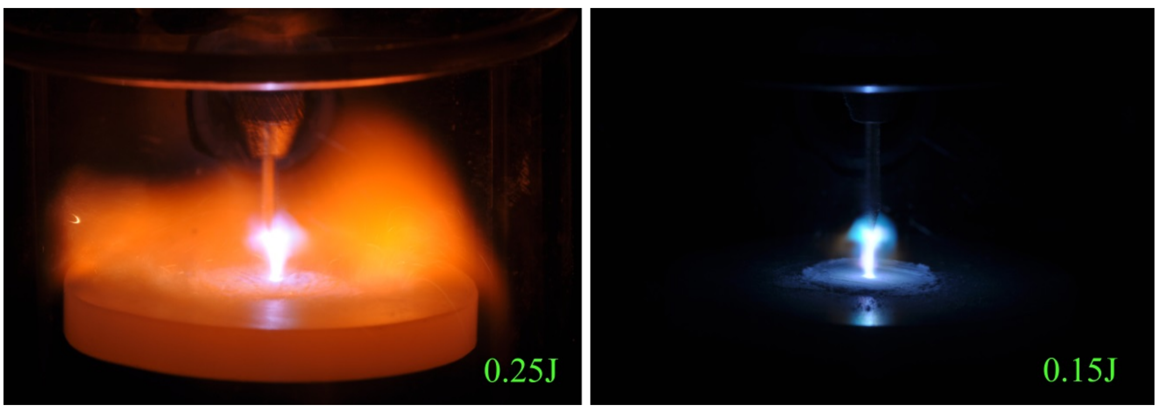

Figure 21. MM2594-48 TIL+1 (Go) and TIL (No Go) level responses

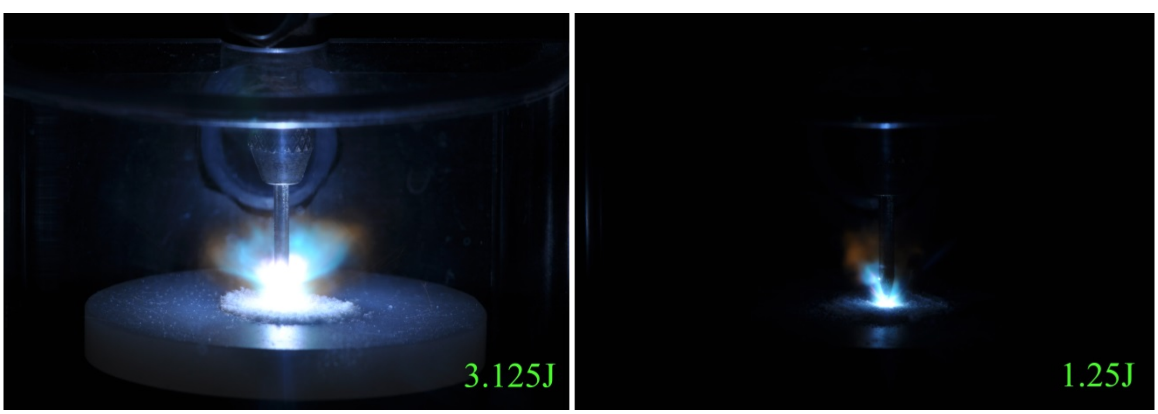

Figure 22. DMR-1103-#1-38 TIL+1 (Go) and TIL (No Go) level responses

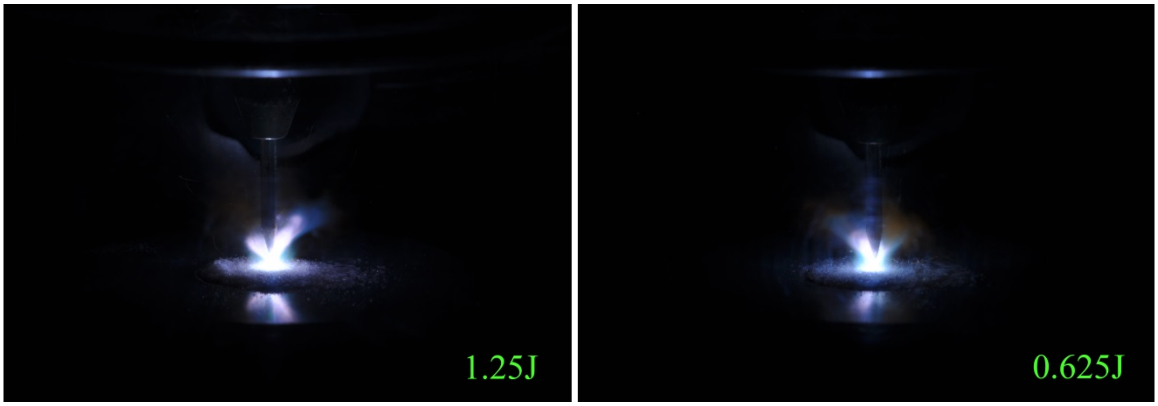

Figure 23. DMR-1103-#1-40 TIL+1 (Go) and TIL (No Go) level responses

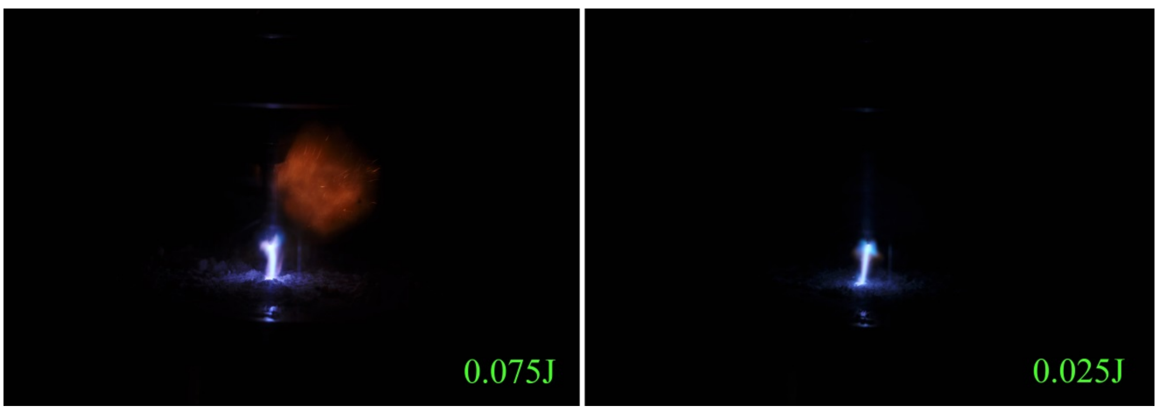

Figure 24. DMR-1103-#1-44 TIL+1 (Go) and TIL (No Go) level responses

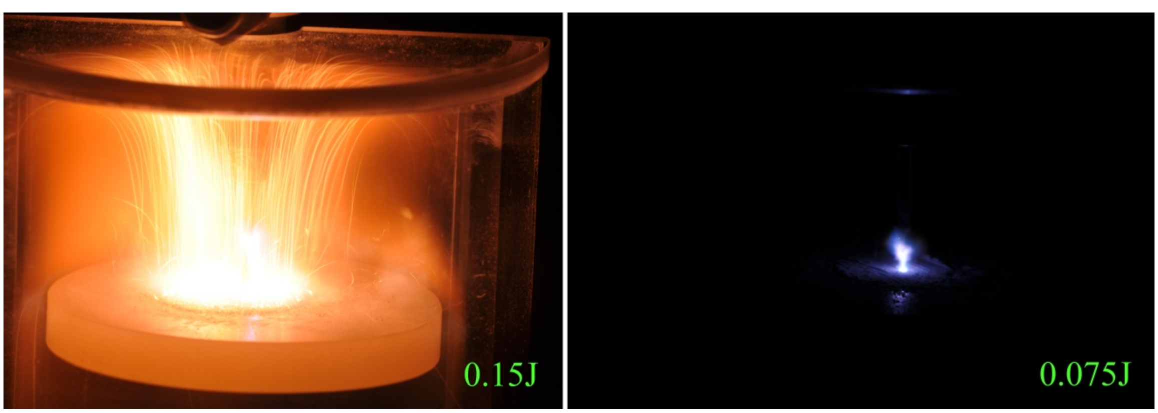

Figure 25. DMR-1103-#1-45 TIL+1 (Go) and TIL (No Go) level responses

4 Summary

All but one of the CL-20 lots displayed impact sensitivities lying approximately between those of dry, mil-spec PETN and RDX. The exception, MM2594-48, showed significantly less sensitivity to impact. The highest sensitivity lot, DMR-1103-#1-40, was equivalent to PETN. This lot also had the largest mean particle size. This is likely due to the crushing of the larger crystals during impact, leading to a greater frequency of hotspot formation.

None of the examined lots displayed any exceptionally large variations in sensitivity to friction. All materials behaved slightly less sensitive than PETN, though more sensitive than RDX.

Traditionally, sensitivity to ESD is more heavily influenced by particle size than friction and impact. The test results of these variations of CL-20 support this assertion. The lots with the larger particle sizes, DMR-1103-#1-38 and -40, showed the lowest ESD sensitivity. ESD sensitivity increased as the particle size decreased, with several lots showing a slightly increased sensitivity compared to dry PETN.

5 References

1. *Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria*. 5th ed. 2009, New York and Geneva: United Nations.
2. MIL-STD-1751A, *Safety and Performance Tests for the Qualification of Explosives*. 2001.
3. Whinnery, L., et al., *SAND2013-3630: Imaging Indicator for ESD Safety Testing*. 2013, Sandia National Laboratories.
4. Dixon, W. and A. Mood, *A Method for Obtaining and Analyzing Sensitivity Data.* Journal of the American Statistical Association, 1948. **43**(241): p. 109-126.
5. MIL-P-387C, *Pentaerythritol Tetranitrate (PETN)*. 1976.
6. MIL-DTL-398D, *RDX (Cyclotrimethylenetrinitramine)*. 1996.

6 Appendix 1: Impact Sensitivity Test Data

Impact Sensitivity Test Results

Tools: Type-12A	Date: 6-18-15	Material: CL-20, MM2545-40
Striker: 2.5kg	RH (%): 43.7	Sample size: 35±3mg
Impactor: 2.5kg	Temp (°C): 23.8	Notes: - static/clumpy/sticky material
Sandpaper: 180A Garnet	Operator: J. Phillips	

Run #	Ht. (cm)	Go	No Go	Comments
1	50	X		Report, flash, smoke, ~50% sandpaper destroyed
2	30	X		" " , ~25% " "
3	20		O	
4	25	X		" "
5	24	X		" " ~50% " "
6	23	X		" " ~60% " "
7	22	X		" " sandpaper destroyed
8	21		O	
9	22	X		" " 80% paper destroyed
10	21		O	
11	22	X		" " 25% " "
12	21		O	
13	22		O	
14	23		O	
15	24	X		" " 80% " "
16	23	X		" " 50% " "
17	22	X		" " 100% " "
18	21	X		" " 75% " "
19	20		O	
20	21		O	
21	22	X		" " 50% " "
22	21	X		" " 90% " "
23	20		O	
24	21		O	
25				
26				
27				H_{50} = 21.5 ± 1.3 cm
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				

Impact Sensitivity Test Results

Tools: 12A	**Date:** 6-15-15	**Material:** CL-20
Striker: 2.5 kg	**RH (%):** 48.2	**Sample size:** 35 ± 3 mg
Impactor: 2.5 kg	**Temp (°C):** 22.8	**Notes:**
Sandpaper: 180A	**Operator:** J. Phillips	MM 2594-48 blend

Run #	Ht. (cm)	Go	No Go	Comments
1	30		O	
2	50		O	
3	80	X		Report, flash, smoke, paper torn (setting) → >75%
4	70		O	
5	75	X		" "
6	74	X		" "
7	73	X		" "
8	72	X		" "
9	71		O	
10	72		O	
11	73		O	
12	74	X		" "
13	73	X		" "
14	72	X		" "
15	71		O	
16	72		O	
17	73		O	
18	74	X		" "
19	73		O	
20	74	X		" "
21	73		O	
22	74	X		" "
23	73	X		" "
24	72	X		" "
25	71		O	
26	72		O	
27				
28				
29				
30				H_{50} = 72.6 ± 1.2 cm
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				

Impact Sensitivity Test Results

Tools: Type 12A	Date: 4-4-15	Material: CL-20 (DMR-1103-#1-38)
Striker: 2.5 kg	RH (%): 46.2	Sample size: 35 ± 2 mg
Impactor: 2.5 kg	Temp (°C): 23.6	Notes:
Sandpaper: 180A Garnet	Operator: J. Phillips	Low density, free-flowing white powder

Run #	Ht. (cm)	Go	No Go	Comments
1	20	X		Report, Flash, smoke, sandpaper 100% destroyed
2	15		O	
3	16		O	
4	17		O	
5	18		O	
6	19		O	
7	20		O	
8	21	X		" "
9	20	X		" "
10	19	X		" " sandpaper 80% destroyed
11	18		O	
12	19		O	
13	20		O	
14	21	X		" "
15	20		O	
16	21		O	
17	22	X		" " 95% "
18	21		O	
19	22		O	
20	23	X		" "
21	22	X		" "
22	21	X		" " 100% "
23	20		O	
24	21		O	
25	22	X		" " 75% "
26	21		O	
27				
28				
29				$H_{50} = 20.6 \pm 2.1$ cm
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				

Impact Sensitivity Test Results

Tools: Type-12A	Date: 8-19-15	Material: CL-20 (DMR-1103-#1-40)
Striker: 2.5kg	RH (%): 41.2	Sample size: 35 ± 2 mg
Impactor: 2.5kg	Temp (°C): 24.7	Notes:
Sandpaper: (80)A garnet	Operator: J.Phillips	- Small, granular powder (white)

Run #	Ht. (cm)	Go	No Go	Comments
1	30	X		Report, Flash, smoke, Sandpaper 3/4 destroyed
2	25	X		" "
3	20	X		" " 1/2 destroyed
4	15	X		" " ALL destroyed
5	10		O	
6	11		O	
7	12		O	
8	13		O	
9	14	X		" "
10	13		O	
11	14	X		" " 1/2 destroyed
12	13		O	
13	14		O	
14	15		O	
15	16	X		" " ALL destroyed
16	15		O	
17	16	X		" " 1/2 destroyed
18	15	X		" " 3/4 destroyed
19	14		O	
20	15		O	
21	16	X		" " 1/2 destroyed
22	15		O	
23	16	X		" "
24	15		O	
25	16	X		" " 90% destroyed
26	15		O	
27	16	X		" " 1/2 destroyed
28				
29				
30				
31				
32				H_{50} = 14.9 ± 1.1 cm
33				
34				
35				
36				
37				
38				
39				
40				

Impact Sensitivity Test Results

Tools: Type-12A	**Date:** 8-4-15	**Material:** CL-20 DMR-1103-#1-44
Striker: 2.5kg	**RH (%):** 47.7	**Sample size:** 35±2 mg
Impactor: 2.5kg	**Temp (°C):** 22.8	**Notes:** - attempted β-CL-20 production
Sandpaper: 180 A Garnet	**Operator:** J. Phillips	- pieces of gently compacted powder - easily broken up w/spatula

Run #	Ht. (cm)	Go	No Go	Comments
1	50	X		Report, smoke, sandpaper 3/4 destroyed
2	30	X		" " 1/2 "
3	25	X		" " + Flash
4	20		O	
5	21	X		" " 1/4 " "
6	20	X		" " 3/4 " "
7	19		O	
8	20		O	
9	21		O	
10	22	X		" " 1/4 " "
11	21	X		" "
12	20		O	
13	21	X		" "
14	20		O	" "
15	21	X		" " 3/4 " "
16	20		O	
17	21	X		" " 1/4 " "
18	20	X		" " 3/4 " "
19	19	X		" " 1/4 " no flash
20	18	X		" "
21	17	X		" "
22	16		O	
23	17	X		" 3/4 " + Flash
24	16		O	
25				
26				$H_{50} = 19.6 \pm 4.9$
27				
28				
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35				
36				
37				
38				
39				
40				

Impact Sensitivity Test Results

Tools: Type-12A	Date: 8-5-15	Material: LL-20, DMR-1103-#1-4S
Striker: 2.5kg	RH (%): 42.2	Sample size: 25±2 mg
Impactor: 2.5kg	Temp (°C): 24.4	Notes:
Sandpaper: 180A Garnet	Operator: J. Phillips	- low density, white powder - handles easily, no static cling

Run #	Ht. (cm)	Go	No Go	Comments
1	30	X		Report, flash, smoke, sandpaper 1/2 destroyed
2	25		O	
3	26		O	
4	27	X		" " ALL destroyed
5	26		O	
6	27	X		" "
7	26	X		" "
8	25	X		" "
9	24	X		" "
10	23		O	
11	24		O	
12	25		O	
13	26		O	
14	27	X		" " 3/4 destroyed
15	26	X		" "
16	25		O	
17	26	X		" "
18	25		O	
19	26	X		" "
20	25		O	
21	26	X		" "
22	25		O	
23	26	X		" "
24				
25				
26				
27				
28				
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$H_{50} = 25.5 \pm 1.3$ cm

7 Appendix 2: Friction Sensitivity Test Data

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
12.0	X																				Snap, smoke, jetting
8.4	X																				" "
6.0	O	O	O	O	O	O	O	O	O	O	O	X									crack, jetting
8.0	O	O	X																		" "
7.2	O	X																			crackle, smoke
5.6	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	TIL (0 of 20) = 56 N

Material:	CL-20 MM2545-40	Operator:	J. Phillips
Date:	6-25-15	Temp (°C):	23.7
		RH (%):	53.4

Go	X
No Go	O

Notes:
- Lots of static cling
- Soft, easily broken clumps in powder

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
24.0	X																				SNAP!, smoke, jetting
16.0	X																				crackle, smoke
12.8	X																				snap, smoke, jetting
11.2	X																				jetting, snap
10.8	O	X																			snap, jetting
9.6	X																				" "
8.4	O	O	O	O	O	O	X														snap
8.0	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	

Material:	CL-20	Operator:	J. Phillips
Date:	6-16-15	Temp:	22.8 °C
		RH:	53.8 %

Go	X
No Go	O

Notes: Blend MM2594-48

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
8.0	O	O	O	O	O	O	X														crackle
8.4	O	O	O	O	O	O	O	O	X												snap smoke, ejecta
9.6	O	O	O	O	O	O	O	O	O	O	O	O	X								crackle, smoke
10.8	X																				crackle, smoke
7.2	O	O	X																		SNAP! ejecta
6.4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	
																					TIL (0 of 20) @ 64N

Material:	CL-20 (DMR-1103-#1-38)	Operator:	J. Phillips
Date:	9-4-15	Temp (°C):	23.6
		RH (%):	46.3

Go	X
No Go	O

Notes: Low density, free-flowing white powder

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
10.8	O	O	O	O																	CRACK! ejecta flash
11.2	O	X																			" " flash
12.0	X																				CRACK! ejecta
9.6	X																				" "
8.0	X																				snap
7.2	O	O	O	O	O	O	O	O	O	O	X										pop, ejecta
6.4	O	O	O	O	O	X															CRACK! ejecta
6.0	O	O	O	O	O	X															crackle, smoke
5.6	O	O	O	O	O	O	O	O	O	O	X										pop, ejecta, smoke
5.4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	
																					TIL 0 of 20 @ 54N

Material:	CL-20 (DMR-1103-#1-40)	Operator:	J.Phillips
Date:	8-20-15	Temp (°C):	24.6
		RH (%):	44.3

Go	X
No Go	O

Notes:

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
10.8	X																				SNAP! ejecta
9.6	X																				Crackle, ejecta
8.4	O	X																			" "
8.0	O	X																			snap
7.2	O	O	O	X																	snap; ejecta
6.4	O	O	O	O	O	X															crack
6.0	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	TIL 0 of 20 at 6.0 kg

Material: CL-20 (DMR-1103-#1-44)
Date: 8-6-15
Operator: J. Phillips
Temp (°C): 24.4
RH (%): 41.2

Go	X
No Go	O

Notes:

BAM Friction Test Results

Load (Kg)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Comments
10.8	X																				snap
9.6	O	O	O	O	O	X															crackle
8.4	X																				snap
8.0	O	X																			SNAP! + ejecta
7.2	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	TIL (0 of 20) at 7.2 kg

Material: CL-20 (DMR-1103-#1-4 s)
Date: 8-6-15
Operator: J. Phillips
Temp (°C): 24.4
RH (%): 41.2

Go	X
No Go	O

Notes: - no static; handles easily

8 Appendix 3: ESD Sensitivity Test Data

ABL ESD Test Results

Cap. (µF)	Energy (J)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Blank Image
0.05	0.625	X																				1
Run Ref. Image →		2																				
0.02	0.25	X																				3
Run Ref. Image →		4																				
0.012	0.15	O	X																			5
Run Ref. Image →		6	7																			
0.006	0.075	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	8
Run Ref. Image →		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Run Ref. Image →																						
Run Ref. Image →																						
Run Ref. Image →																						
Run Ref. Image →																						
Run Ref. Image →																						

Material:	CL-20, MM2545-40	**Temp (°C):**	22.6
Date:	6-17-15	**RH (%):**	54.2
Operator:	J. Phillips	**Test Type:**	Approaching needle

Notes:
- Material received dry
- Very clumpy; clumps may be broken up with spatula
- Static cling (compared to Batch-48)

TIL (0 of 20) at 0.075 J

ABL ESD Gas Analyzer Results (ppm)

Cap. (µF)	Energy (J)		Run #, Pre-shot/Post-shot 1	2	3	4	5	6	7	8	9	10
0.05	0.625	CO_2	357/ >	/	/	/	/	/	/	/	/	/
		CO	37.9/ >	/	/	/	/	/	/	/	/	/
0.02	0.25	CO_2	341/ >	/	/	/	/	/	/	/	/	/
		CO	38.2/ >	/	/	/	/	/	/	/	/	/
0.012	0.15	CO_2	386/396	380/ >	/	/	/	/	/	/	/	/
		CO	38.4/42.2	38.1/ >	/	/	/	/	/	/	/	/
0.006	0.075	CO_2	393/398	394/396	394/401	404/404	408/411	407/405	385/386	383/382	382/382	381/417
		CO	38.3/40.2	38.2/40.1	38.1/41.5	38.0/42.6	38.2/39.6	38.2/43.4	38.0/39.5	38.0/41.4	38.1/40.4	38.1/42.1
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Cap. (µF)	Energy (J)		11	12	13	14	15	16	17	18	19	20
0.006	0.075	CO_2	389/404	382/385	382/385	383/386	392/393	387/392	388/383	375/384	372/371	377/378
		CO	38.0/41.7	38.0/40.9	38.0/40.7	38.0/40.2	38.0/43.0	38.0/44.7	37.9/40.3	38.0/41.0	38.0/40.1	38.1/40.2
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Material:	CL-20, MM2545-40	**Temp (°C):**	22.6
Date:	6-17-15	**RH (%):**	54.2
Operator:	J. Phillips	**Test Type:**	Approaching needle

ABL ESD Test Results

Cap. (µF)	Energy (J)	Run # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.05	0.625	X																			
Run Ref. Image →		2																			
0.012	0.15	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Run Ref. Image →		4	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0.02	0.25	O	O	X																	
Run Ref. Image →		6	7	8																	
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					

Blank Image
1
3
5

Material:	CL-20
Date:	6-16-15

Temp (°~~F~~ C):	22.7
RH (%):	55.3

Operator:	J. Phillips
Test Type:	Approaching needle

TIL (0 of 20)
0.15 J

Notes:
- blend MM2594-48

ABL ESD Gas Analyzer Results (ppm)

Cap. (µF)	Energy (J)		Run #, Pre-shot/Post-shot 1	2	3	4	5	6	7	8	9	10
0.05	0.625	CO_2	387 / >	/	/	/	/	/	/	/	/	/
		CO	- / >	/	/	/	/	/	/	/	/	/
0.012	0.15	CO_2	400 / 403	394 / 399	388 / 404	393 / 403	387 / 396	393 / 404	380 / 382	379 / 392	377 / 405	378 / 385
		CO	43.9 / 44.3	42.7 / 46.7	42.1 / 47.2	42.0 / 46.1	41.8 / 45.1	41.8 / 43.2	41.0 / 43.5	40.9 / 44.4	40.8 / 44.9	40.8 / 43.1
0.02	0.25	CO_2	391 / ~~384~~ 402	392 / 401	389 / >	/	/	/	/	/	/	/
		CO	43.1 / 43.9	43.0 / 46.3	42.8 / 83.2	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Cap. (µF)	Energy (J)		11	12	13	14	15	16	17	18	19	20
0.012	0.15	CO_2	379 / 394	387 / 395	387 / 397	388 / 406	400 / 396	391 / 396	384 / 390	385 / 390	387 / 399	386 / 394
		CO	40.6 / 43.3	40.4 / 44.1	40.3 / 44.1	39.9 / 44.0	40.1 / 41.8	39.8 / 41.5	39.7 / 42.8	39.8 / 42.6	39.7 / 43.5	39.8 / 41.5
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Material:	CL-20, blend MM2594-48	Temp (°C):	22.7	Operator:	J. Phillips
Date:	6-16-15	RH (%):	55.3	Test Type:	Approaching needle

ABL ESD Test Results

Cap. (µF)	Energy (J)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.5	6.25	X																			
Run Ref. Image →		2																			
0.1	1.25	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Run Ref. Image →		4	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0.25	3.125	X																			
Run Ref. Image →		6																			
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					
Run Ref. Image →																					

TIL (0 of 20) @ 1.25 J

Blank Image
1
3
5

Material:	CL-20 (DMR-1103-#1-38)	Temp (°C):	23.4
Date:	9-4-15	RH (%):	47.8
Operator:	J. Phillips	Test Type:	Approaching needle

Notes:
low density, free-flowing white powder

ABL ESD Gas Analyzer Results (ppm)

Run #, Pre-shot/Post-shot

Cap. (µF)	Energy (J)		1	2	3	4	5	6	7	8	9	10
0.5	6.25	CO_2	401 / 507	/	/	/	/	/	/	/	/	/
		CO	6 / 30	/	/	/	/	/	/	/	/	/
0.1	1.25	CO_2	411 / 439	411 / 430	409 / 430	416 / 437	415 / 440	411 / 433	410 / 432	415 / 437	417 / 430	418 / 441
		CO	6 / 18	5 / 14	5 / 14	5 / 14	5 / 18	5 / 11	5 / 13	5 / 15	5 / 9	5 / 15
0.25	3.125	CO_2	411 / 542	/	/	/	/	/	/	/	/	/
		CO	5 / 48	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Cap. (µF)	Energy (J)		11	12	13	14	15	16	17	18	19	20
0.1	1.25	CO_2	417 / 449	417 / 440	423 / 445	420 / 440	418 / 438	407 / 430	405 / 441	411 / 430	408 / 440	411 / 448
		CO	5 / 16	5 / 19	5 / 19	5 / 18	5 / 15	5 / 12	5 / 15	5 / 10	5 / 20	5 / 21
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/
		CO_2	/	/	/	/	/	/	/	/	/	/
		CO	/	/	/	/	/	/	/	/	/	/

Material:	CL-20 (DMR-1103-#1-38)	Temp (°C):	23.4
Date:	9-4-15	RH (%):	47.8
Operator:	J. Phillips	Test Type:	Approaching needle